SECTION 7 - MEASUREMENT AND ANALYSIS EQUIPMENT

Current technology noise recording and analysis equipment employing digital techniques which offer greater flexibility and precision than before are not catered for in the specification of equipment used in noise certification and described in Annex 16, Volume 1, Appendix 2, Section 3.

This section describes new instrumentation standards which have been approved by CAEP Working Group 1 to replace the existing Section 3 of Appendix 2 of Annex 16, Volume 1 and thereby enable the increasing use of digital instrumentation. This section will be removed from the Environmental Technical Manual when it is adopted into the Annex.

7.1 DEFINITIONS

For the purposes of this section the following definitions apply: -

7.1.1 **measurement system**: the combination of instruments used for the measurement of sound pressure levels, including a sound calibrator, windscreen, microphone system, signal recording and conditioning devices, and one-third octave band analysis system.

Note. - Practical installations may include a number of microphone systems, the outputs from which are recorded simultaneously by a multi-channel recording/analysis device via signal conditioners as appropriate. For the purpose of this section, each complete measurement channel is considered to be a measurement system to which the requirements apply accordingly.

7.1.2 **microphone system**: the components of the measurement system which produce an electrical output signal in response to a sound pressure input signal, and which generally include a microphone, a preamplifier, extension cables, and other devices as necessary.

7.1.3 **sound incidence angle**: in degrees, an angle between the principal axis of the microphone, as defined in IEC 61094-3[1] and IEC 61094-4[2], as amended and a line from the sound source to the centre of the diaphragm of the microphone.

Note. - When the sound incidence angle is 0°, the sound is said to be received at the microphone at "normal (perpendicular) incidence"; when the sound incidence angle is 90°, the sound is said to be received at "grazing incidence".

7.1.4 **reference direction**: in degrees, the direction of sound incidence specified by the manufacturer of the microphone, relative to a sound incidence angle of 0°, for which the free-field sensitivity level of the microphone system is within specified tolerance limits.

7.1.5 **free-field sensitivity of a microphone system**: in volts per pascal, for a sinusoidal plane progressive sound wave of specified frequency, at a specified sound-incidence angle, the

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[1] IEC 61094-3: 1995 entitled "Measurement microphones – Part 3: Primary method for free-field calibration of laboratory standard microphones by the reciprocity technique"

[2] IEC 61094-4: 1995 entitled "Measurement microphones – Part 4: Specifications for working standard microphones"
These IEC publications may be obtained from the Bureau central de la Commission électrotechnique internationale, 1 rue de Varembé, Geneva, Switzerland

quotient of the root mean square voltage at the output of a microphone system and the root mean square sound pressure that would exist at the position of the microphone in its absence.

7.1.6 **free-field sensitivity level of a microphone system**: in decibels, twenty times the logarithm to the base ten of the ratio of the free-field sensitivity of a microphone system and the reference sensitivity of one volt per pascal.

Note. - The free-field sensitivity level of a microphone system may be determined by subtracting the sound pressure level (in decibels re 20 mPa) of the sound incident on the microphone from the voltage level (in decibels re 1 V) at the output of the microphone system, and adding 93.98 dB to the result.

7.1.7 **time-average band sound pressure level**: in decibels, ten times the logarithm to the base ten, of the ratio of the time mean square of the instantaneous sound pressure during a stated time interval and in a specified one-third octave band, to the square of the reference sound pressure of 20μPa.

7.1.8 **level range**: in decibels, an operating range determined by the setting of the controls that are provided in a measurement system for the recording and one-third octave band analysis of a sound pressure signal. The upper boundary associated with any particular level range shall be rounded to the nearest decibel.

7.1.9 **calibration sound pressure level**: in decibels, the sound pressure level produced, under reference environmental conditions, in the cavity of the coupler of the sound calibrator that is used to determine the overall acoustical sensitivity of a measurement system.

7.1.10 **reference level range**: in decibels, the level range for determining the acoustical sensitivity of the measurement system and containing the calibration sound pressure level.

7.1.11 **calibration check frequency**: in hertz, the nominal frequency of the sinusoidal sound pressure signal produced by the sound calibrator.

3.1.12 **level difference**: in decibels, for any nominal one-third octave midband frequency, the output signal level measured on any level range minus the level of the corresponding electrical input signal.

7.1.13 **reference level difference**: in decibels, for a stated frequency, the level difference measured on a level range for an electrical input signal corresponding to the calibration sound pressure level, adjusted as appropriate, for the level range.

7.1.14 **level non-linearity**: in decibels, the level difference measured on any level range, at a stated one-third octave nominal midband frequency, minus the corresponding reference level difference, all input and output signals being relative to the same reference quantity.

7.1.15 **linear operating range**: in decibels, for a stated level range and frequency, the range of levels of steady sinusoidal electrical signals applied to the input of the entire measurement system, exclusive of the microphone but including the microphone preamplifier and any other signal-conditioning elements that are considered to be part of the microphone system, extending from a lower to an upper boundary, over which the level non-linearity is within specified tolerance limits.

Note. - It is not necessary to include microphone extension cables as configured in the field.

7.1.16 **windscreen insertion loss**: in decibels, at a stated nominal one-third octave midband frequency, and for a stated sound incidence angle on the inserted microphone, the indicated sound pressure level without the windscreen installed around the microphone minus the sound pressure level with the windscreen installed.

7.2 REFERENCE ENVIRONMENTAL CONDITIONS

7.2.1 The reference environmental conditions for specifying the performance of a measurement system are:

- air temperature	23°C
- static air pressure	101.325 kPa
- relative humidity	50 %

7.3 GENERAL

Note. - Measurements of aircraft noise that utilise instruments that conform to the specifications of this section yield one-third octave band sound pressure levels as a function of time, for the calculation of effective perceived noise level as described in Annex 16, Volume 1, Appendix 2, Section 4.

7.3.1 The measurement system shall consist of equipment approved by the certificating authority and equivalent to the following:

a) a windscreen; (see 7.4)

b) a microphone system (see 7.5);

c) a recording and reproducing system to store the measured aircraft noise signals for subsequent analysis (see 7.6);

d) a one-third octave band analysis system (see 7.7);

e) calibration systems to maintain the acoustical sensitivity of the above systems within specified tolerance limits (see 7.8).

7.3.2 For any component of the measurement system that converts an analog signal to digital form, such conversion shall be performed so that the levels of any possible aliases or artefacts of the digitisation process will be less than the upper boundary of the linear operating range by at least 50 dB at any frequency less than 12.5 kHz. The sampling rate shall be at least 28 kHz. An anti-aliasing filter shall be included before the digitisation process.

7.4 WINDSCREEN

7.4.1 In the absence of wind and for sinusoidal sounds at grazing incidence, the insertion loss caused by the windscreen of a stated type installed around the microphone shall not exceed ±1.5 dB at nominal one-third octave midband frequencies from 50 Hz to 10 kHz inclusive.

7.5 MICROPHONE SYSTEM

7.5.1 The microphone system shall conform to the specifications in 7.5.2 to 7.5.4. Various microphone systems may be approved by the certificating authority on the basis of demonstrated equivalent overall electroacoustical performance. Where two or more microphone systems of the same type are used, demonstration that at least one system conforms to the specifications in full is sufficient to demonstrate conformance.

Note. - This demonstration of equivalent performance does not eliminate the need to calibrate and check each system as defined in 7.9.

7.5.2 The microphone shall be mounted with the sensing element 1.2 m (4 ft) above the local ground surface and shall be oriented for grazing incidence, i.e., with the sensing element substantially in the plane defined by the predicted reference flight path of the aircraft and the measuring station. The microphone mounting arrangement shall minimise the interference of the supports with the sound to be measured. Figure 12 illustrates sound incidence angles on a microphone.

7.5.3 The free-field sensitivity level of the microphone and preamplifier in the reference direction, at frequencies over at least the range of one-third-octave nominal midband frequencies from 50 Hz to 5 kHz inclusive, shall be within ±1.0 dB of that at the calibration check frequency, and within ±2.0 dB for nominal midband frequencies of 6.3 kHz, 8 kHz and 10 kHz.

7.5.4 For sinusoidal sound waves at each one-third octave nominal midband frequency over the range from 50 Hz to 10 kHz inclusive, the free-field sensitivity levels of the microphone system at sound incidence angles of 30°, 60°, 90°, 120° and 150°, shall not differ from the free-field sensitivity level at a sound incidence angle of 0° ("normal incidence") by more than the values shown in Table 7-1. The free-field sensitivity level differences at sound incidence angles between any two adjacent sound incidence angles in Table 7-1 shall not exceed the tolerance limit for the greater angle.

Nominal midband frequency kHz	Maximum difference between the free-field sensitivity level of a microphone system at normal incidence and the free-field sensitivity level at specified sound incidence angles dB Sound Incidence angle degrees				
	30	60	90	120	150
0.05 to 1.6	0.5	0.5	1.0	1.0	1.0
2.0	0.5	0.5	1.0	1.0	1.0
2.5	0.5	0.5	1.0	1.5	1.5
3.15	0.5	1.0	1.5	2.0	2.0
4.0	0.5	1.0	2.0	2.5	2.5
5.0	0.5	1.5	2.5	3.0	3.0
6.3	1.0	2.0	3.0	4.0	4.0
8.0	1.5	2.5	4.0	5.5	5.5
10.0	2.0	3.5	5.5	6.5	7.5

Table 7-1 Microphone Directional Response Requirements

7.6 RECORDING AND REPRODUCING SYSTEMS

7.6.1 A recording and reproducing system, such as a digital or analogue magnetic tape recorder, a computer-based system or other permanent data storage device, shall be used to store sound pressure signals for subsequent analysis. The sound produced by the aircraft shall be recorded in such a way that a record of the complete acoustical signal is retained. The recording and reproducing systems shall conform to the specifications in 7.6.2 to 7.6.9 at the recording speeds and/or data sampling rates used for the noise certification tests. Conformance shall be demonstrated for the frequency bandwidths and recording channels selected for the tests.

7.6.2 The recording and reproducing systems shall be calibrated as described in 7.9.

Note. - For aircraft noise signals for which the high frequency spectral levels decrease rapidly with increasing frequency, appropriate pre-emphasis and complementary de-emphasis networks may be included in the measurement system. If pre-emphasis is included, over the range of nominal one-third octave midband frequencies from 800 Hz to 10 kHz inclusive, the electrical gain provided by the pre-emphasis network shall not exceed 20 dB relative to the gain at 800 Hz.

7.6.3 For steady sinusoidal electrical signals applied to the input of the entire measurement system exclusive of the microphone system, but including the microphone preamplifier, and any other signal-conditioning elements that are considered to be part of the microphone system, at a selected signal level within 5 dB of that corresponding to the calibration sound pressure level on the reference level range, the time average signal level indicated by the readout device at any one-third octave nominal midband frequency from 50 Hz to10 kHz inclusive shall be within ±1.5 dB of that at the calibration check frequency. The frequency response of a measurement system, which includes components that convert analogue signals to digital form, shall be within ±0.3 dB of the response at 10 kHz over the frequency range from 10 kHz to 11.2 kHz.

Note. - It is not necessary to include microphone extension cables as configured in the field.

7.6.4 For analogue tape recordings, the amplitude fluctuations of a 1 kHz sinusoidal signal recorded within 5 dB of the level corresponding to the calibration sound pressure level shall not vary by more than ±0.5 dB throughout any reel of the type of magnetic tape utilised. Conformance to this requirement shall be demonstrated using a device which has time-averaging properties equivalent to those of the spectrum analyser.

7.6.5 For all appropriate level ranges and for steady sinusoidal electrical signals applied to the input of the measurement system exclusive of the microphone system, but including the microphone preamplifier, and any other signal-conditioning elements that are considered to be part of the microphone system, at one-third-octave nominal midband frequencies of 50 Hz, 1 kHz and 10 kHz, and the calibration check frequency, if it is not one of these frequencies, the level non-linearity shall not exceed ±0.5 dB for a linear operating range of at least 50 dB below the upper boundary of the level range.

Note 1. - Level linearity of measurement system components should be tested according to the methods described in IEC 61265[3] *as amended.*

Note 2. - It is not necessary to include microphone extension cables as configured in the field.

7.6.6 On the reference level range, the level corresponding to the calibration sound pressure level shall be at least 5 dB, but no more than 30 dB less than the upper boundary of the level range.

7.6.7 The linear operating ranges on adjacent level ranges shall overlap by at least 50 dB minus the change in attenuation introduced by a change in the level range controls.

Note. - It is possible for a measurement system to have level range controls that permit attenuation changes of either 10 dB or 1 dB, for example. With 10 dB steps, the minimum overlap required would be 40 dB, and with 1 dB steps the minimum overlap would be 49 dB.

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[3] IEC 61265: 1995 entitled “Instruments for measurement of aircraft noise – Performance requirements for systems to measure one-third-octave band sound pressure levels in noise certification of transport-category aeroplanes”. This IEC publications may be obtained from the Bureau central de la Commission électrotechnique internationale, 1 rue de Varembé, Geneva, Switzerland

7.6.8 Provision shall be made for an overload indication to occur during an overload condition on any relevant level range.

7.6.9 Attenuators included in the measurement system to permit range changes shall operate in known intervals of decibel steps.

7.7 **Analysis systems**

7.7.1 The analysis system shall conform to the specifications in 7.7.2 to 7.7.7 for the frequency bandwidths, channel configurations and gain settings used for analysis.

7.7.2 The output of the analysis system shall consist of one-third octave band sound pressure levels as a function of time, obtained by processing the noise signals (preferably recorded) through an analysis system with the following characteristics:

a) a set of 24 one-third octave band filters, or their equivalent, having nominal midband frequencies from 50 Hz to 10 kHz inclusive;

b) response and averaging properties in which, in principle, the output from any one-third octave filter band is squared, averaged and displayed or stored as time averaged sound pressure levels;

c) the interval between successive sound-pressure level samples shall be 500 ms ±5 ms for spectral analysis with or without SLOW time weighting;

d) for those analysis systems that do not process the sound-pressure signals during the period of time required for readout and / or resetting of the analyser, the loss of data shall not exceed a duration of 5 ms; and

e) the analysis system shall operate in real time from 50 Hz to at least 12 kHz inclusive. This requirement applies to all operating channels of a multi-channel spectral analysis system.

7.7.3 The one-third octave band analysis system shall at least conform to the class 2 electrical performance requirements of IEC 61260[4] as amended, over the range of one-third octave nominal midband frequencies from 50 Hz to 10 kHz inclusive.

Note. - Tests of the one-third octave band analysis system should be made according to the methods described in IEC 612604 or by an equivalent procedure approved by the certificating authority, for relative attenuation, anti-aliasing filters, real time operation, level linearity, and filter integrated response (effective bandwidth).

7.7.4 When SLOW time averaging is performed in the analyser, the response of the one-third octave band analysis system to a sudden onset or interruption of a constant sinusoidal signal at the respective one-third octave nominal midband frequency shall be measured at sampling instants 0.5, 1, 1.5 and 2 s after the onset and 0.5 and 1 s after interruption. The rising response shall be -4 ± 1 dB at 0.5 s, -1.75 ± 0.75 dB at 1 s, -1 ± 0.5 dB at 1.5 s and -0.5 ± 0.5 dB at 2 s relative to the steady-state level. The falling response shall be such that the sum of the output signal levels, relative to the initial steady-state level, and the corresponding rising response reading is -6.5 ± 1 dB, at both 0.5 and 1 s. At subsequent times the sum of the rising and falling responses shall be -7.5 dB or less.

[4] IEC 61260: 1995 entitled " Electroacoustics – Octave-band and fractional-octave-band filters". This IEC publications may be obtained from the Bureau central de la Commission électrotechnique internationale, 1 rue de Varembé, Geneva, Switzerland

This equates to an exponential averaging process (SLOW weighting) with a nominal 1 s time constant (i.e. 2 s averaging time).

7.7.5 When the one-third octave band sound pressure levels are determined from the output of the analyser without SLOW time weighting, SLOW time weighting shall be simulated in the subsequent processing. Simulated SLOW weighted sound pressure levels can be obtained using a continuous exponential averaging process by the following equation:

$$L_S\left(i,k\right)=10\log\left[\left(0.60653\right)10^{0.1L_S\left[i,\left(k-1\right)\right]}+\left(0.39347\right)10^{0.1L\left(i,k\right)}\right]$$

where $L_s(i,k)$ is the simulated SLOW weighted sound pressure level and $L(i,k)$ is the as-measured 0.5 s time average sound pressure level determined from the output of the analyser for the k-th instant of time and the i-th one-third octave band. For k =1, the SLOW weighted sound pressure $L_s[i,(k\text{-}1=0)]$ on the right hand side should be set to 0 dB.

An approximation of the continuous exponential averaging is represented by the following equation for a four sample averaging process for $k \geq 4$:

$$L_s\left(i,k\right)=10\log\left[\left(0.13\right)10^{0.1L\left[i,\left(k-3\right)\right]}+\left(0.21\right)10^{0.1L\left[i,\left(k-2\right)\right]}+\left(0.27\right)10^{0.1L\left[i,\left(k-1\right)\right]}+\left(0.39\right)10^{0.1L\left[i,k\right]}\right]$$

where $L_s(i,k)$ is the simulated SLOW weighted sound pressure level and $L(i,k)$ is the as measured 0.5 s time average sound pressure level determined from the output of the analyser for the k-th instant of time and the i-th one-third octave band.

The sum of the weighting factors is 1.0 in the two equations. Sound pressure levels calculated by means of either equation are valid for the sixth and subsequent 0.5 s data samples, or for times greater than 2.5 s after initiation of data analysis.

Note. – The coefficients in the two equations were calculated for use in determining equivalent SLOW weighted sound pressure levels from samples of 0.5 s time average sound pressure levels. The equations should not be used with data samples where the averaging time differs from 0.5 s.

7.7.6 The instant in time by which a SLOW time weighted sound pressure level is characterised shall be 0.75 s earlier than the actual readout time.

Note. – The definition of this instant in time is required to correlate the recorded noise with the aircraft position when the noise was emitted and takes into account the averaging period of the SLOW weighting. For each ½ second data record this instant in time may also be identified as 1.25 seconds after the start of the associated 2 second averaging period.

7.7.7 The resolution of the sound pressure levels, both displayed and stored, shall be 0.1 dB or better.

7.8 CALIBRATION SYSTEMS

7.8.1 The acoustical sensitivity of the measurement system shall be determined using a sound calibrator generating a known sound pressure level at a known frequency. The sound calibrator shall at least conform to the class 1L requirements of IEC 60942[5] as amended.

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[5] IEC 60942: 1997 entitled " Electroacoustics - Sound calibrators". This IEC publications may be obtained from the Bureau central de la Commission électrotechnique internationale, 1 rue de Varembé, Geneva, Switzerland

7.9 CALIBRATION AND CHECKING OF SYSTEM

7.9.1 Calibration and checking of the measurement system and its constituent components shall be carried out to the satisfaction of the certificating authorities by the methods specified in 7.9.2 to 7.9.10. The calibration adjustments, including those for environmental effects on sound calibrator output level, shall be reported to the certificating authority and applied to the measured one-third-octave sound pressure levels determined from the output of the analyzer. Data collected during an overload indication are invalid and shall not be used. If the overload condition occurred during recording, the associated test data shall be considered as invalid, whereas if the overload occurred during analysis the analysis shall be repeated with reduced sensitivity to eliminate the overload.

7.9.2 The free field frequency response of the microphone system may be determined by use of an electrostatic actuator in combination with manufacturer's data or by tests in an anechoic free-field facility. The correction for frequency response shall be determined within 90 days of each test series. The correction for non-uniform frequency response of the microphone system shall be reported to the certificating authority and applied to the measured one-third octave band sound pressure levels determined from the output of the analyser.

7.9.3 When the angles of incidence of sound emitted from the aircraft are within ±30° of grazing incidence at the microphone (see Figure 12), a single set of free-field corrections based on grazing incidence is considered sufficient for correction of directional response effects. For other cases, the angle of incidence for each ½ second sample shall be determined and applied for the correction of incidence effects.

7.9.4 For analogue magnetic tape recorders, each reel of magnetic tape shall carry at least 30 seconds of pink random or pseudo-random noise at its beginning and end. Data obtained from analogue tape-recorded signals shall be accepted as reliable only if level differences in the 10 kHz one-third-octave-band are not more than 0.75 dB for the signals recorded at the beginning and end.

7.9.5 The frequency response of the entire measurement system while deployed in the field during the test series, exclusive of the microphone, shall be determined at a level within 5 dB of the level corresponding to the calibration sound pressure level on the level range used during the tests for each one-third octave nominal midband frequency from50 Hz to10 kHz inclusive, utilising pink random or pseudo-random noise. The output of the noise generator shall be determined by a method traceable to a national standards laboratory within 6 months of each test series and tolerable changes in the relative output from the previous calibration at each one-third octave band shall be not more than 0.2 dB. The correction for frequency response shall be reported to the certificating authority and applied to the measured one-third octave sound pressure levels determined from the output of the analyser.

7.9.6 The performance of switched attenuators in the equipment used during noise certification measurements and calibration shall be checked within six months of each test series to ensure that the maximum error does not exceed 0.1 dB.

7.9.7 The sound pressure level produced in the cavity of the coupler of the sound calibrator shall be calculated for the test environmental conditions using the manufacturer's supplied information on the influence of atmospheric air pressure and temperature. The sound pressure level shall be used to establish the acoustical sensitivity of the measurement system. The output of the sound calibrator shall be determined by a method traceable to a national standards laboratory within 6 months of each test series and tolerable changes in output from the previous calibration shall be not more than 0.2 dB.

7.9.8 Sufficient sound pressure level calibrations shall be made during each test day to ensure that the acoustical sensitivity of the measurement system is known at the prevailing environmental conditions corresponding with each test series. The measurement system shall be considered satisfactory if the difference is not greater than 0.5 dB between the acoustical sensitivity levels recorded immediately before and immediately after each test series on a given day. The 0.5 dB limit applies after any atmospheric pressure corrections have been determined for the calibrator output level. The arithmetic mean of the before and after measurements shall be used to represent the acoustical sensitivity level of the measurement system for that test series. The calibration corrections shall be reported to the certificating authority and applied to the measured one-third octave band sound pressure levels determined from the output of the analyser.

7.9.9 Each recording medium, such as a reel, cartridge, cassette, or diskette, shall carry a sound pressure level calibration of at least 10 seconds duration at its beginning and end.

7.9.10 The free-field insertion loss of the windscreen for each one-third octave nominal midband frequency from 50 Hz to 10 kHz inclusive shall be determined with sinusoidal sound signals at appropriate incidence angles on the inserted microphone. For a windscreen which is undamaged and uncontaminated the insertion loss may be taken from manufacturer's data. In addition the insertion loss of the windscreen may be determined by a method traceable to a national standards laboratory within 6 months of each test series and tolerable changes in the insertion loss from the previous calibration at each one-third-octave frequency band shall be not more than 0.4 dB. The correction for the free-field insertion loss of the windscreen shall be reported to the certificating authority and applied to the measured one-third octave sound pressure levels determined from the output of the analyser.

7.10 ADJUSTMENTS FOR AMBIENT NOISE

7.10.1 The ambient noise, including both acoustical background and electrical noise of the measurement system, shall be recorded for at least 10s at the measurement points with the system gain set at the levels used for the aircraft noise measurements, at appropriate times during each test day. The ambient noise shall be representative of the acoustical background that exits during the flyover test run. The recorded aircraft noise data shall be accepted only if the ambient noise levels when analysed in the same way and quoted in PNL (see Paragraph 4.1.3(a) of Appendix 2, Annex 16, Volume 1) are at least 20 dB below the maximum PNL of the aircraft.

7.10.2 Aircraft sound pressure levels within the 10 dB-down points (see Paragraph 4.5.1 of Appendix 2, Annex 16, Volume 1) shall exceed the mean ambient noise levels determined above by at least 3 dB in each one-third octave band or be adjusted using the method described in Appendix 3.

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